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Sliding Wear Behavior of Epoxy Based Composites

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Abstract**:** ***Sliding wear behavior of composites basalt-epoxy (BE), carbon-epoxy (CE) & glass-epoxy (GE) were examined using pin on disc-sliding wear for various abrading distances and at constant rpm. Weight loss and specific wear rates were determined depending on the load and abrading distance. With Higher load and abrading distance, higher weight loss, while with increased abrading distance and load decreases in specific wear rates. Compared to GE and CE composite better wear resistance in BE composite was observed. The test specimens are analyzed using the scanning electron microscope (SEM) and shows that glass fiber and carbon fiber suffer more damage than basalt fiber. Good interface adhesion between epoxy and basalt fiber has also been observed, this leads to good resistance to wear. The mechanical properties of epoxy composites strengthened by basalt, carbon and glass fabric were evaluated. Scanning electron microscopy has been utilized to study wear mechanism using worn surface analysis.***

Index Terms**:** ***Basalt, Epoxy, SEM***

I. INTRODUCTION

As a composite material, the combination of two or more materials with better characteristics than individual components. The composite material consists primarily of two, matrix and reinforcement components. Composite classifications are based on these components. The purpose of matrix in case of matrix - based structural composites is that, helps for binding the reinforcement phases and distribution of stress among the components under the applied force. The strengthening phase gives strength and rigidity. The reinforcement is harder, stronger and harder than the matrix in most cases. In general, the reinforcement is a fiber or particulate. Matrix compatibility, thermal stability, density, melting temperature, etc. are the points to be noted in the reinforcement selection. The matrix is the main load - bearing component in composites reinforced with particulates and whiskers. The role of reinforcement is to prevent matrix deformation so as to strengthen the composite by mechanical restraint. This restriction usually depends on the inter-particle spacing ratio to the particle diameter. The reinforcement is the main load-bearing component in continuous fiber-reinforced composites. The metal matrix is used to hold and transfer the reinforcing fibers and distribute the load.

II. MATERIALS

A.Fiber Materials

Fibers are the main reinforcement class because they meet the conditions required and transfer strength to the matrix component that influences and improves composite properties. The earliest fibers known to strengthen the materials are glass fibers, after which ceramic and metal fibers were found and used extensively to make composites more heat - resistant. Because of several factors, fibers are lacking in ideal performance. The mechanical characteristics of matrix, length, shape, orientation and composition of the fibers evaluate the fiber composite performance. Unidirectional loading is observed in a few structures and therefore it is necessary to provide a combination of fiber orientations in composites, especially where the heaviest load is expected.

B. Epoxy Resin

An epoxy resin is defined as a molecule with more than one group of epoxies that can be hardened into a plastic that can be used. Epoxy resins are the most frequently used polymer composite thermal plastic resins. These are a thermal family-establish plastic materials not producing reaction products. They also have good adhesion to other materials, resistance to chemicals and the environment, good chemical properties and insulation.

C.Basalt, carbon, glass materials as fibers

Basalt, carbon and glass fibers are used for this particular study among the various available fiber materials. Basalt fiber is a material made of very fine basalt fibres, which consists of plagioclase, pyroxene and olivine minerals. It is similar to fiberglass, which has better physicomechanical properties than fiberglass, but is much cheaper than carbon fiber. This type of fiber can be generally used in camera tripods. The other two fibers (carbon, glass) are widely used in everyday life, although both are similar in construction, but both have their own specific characteristics. There are many similarities between carbon fiber and fiberglass, but they also have extreme differences. Depending on the circumstances, both materials can be exchanged in certain aspects of the industry.

III.METHODOLOGY

There have been attempts made to study sliding wear behaviour of basalt - epoxy (BE), Carbon-epoxy(CE) and glass–epoxy (GE). Epoxy is used as resin or matrix for the selected fibers. The fabricated material is tested for different loading conditions.

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The methods followed for the present work are as follows

- Fabrication of glass, basalt and carbon fiber reinforced epoxy based composite
- Mechanical properties assessment (tensile, flexural, impact strength, hardness etc.)Wear of composite samples in dry slides under different operating condition.
- On the sliding wear test, the study of sliding distance and load effect.

This work is also expected to introduce a new class of tribological applications of polymer composites.

III. TESTING

A. Specimen Preparation

A tribometer of pin on a disk type consists of a stationary pin in contact with a rotating disk under an applied load. The pin can simulate a specific contact in any shape, but spherical tips are often used to simplify the geometry of the contact. The ratio between the friction force and the loading force on the pin determines the coefficient of friction.
For present study, 150 g / m^2 of basalt plain weaving fabrics, woven E-glass fabric (360 g / m^2) with a diameter of 10-15 µm carbon fabric (220g /m^2). The investigated epoxy matrix is an epoxy resin of medium viscosity (LY556) with a density of 1,15 - 1,20g / cm3 and a healing hardener of room temperature (HY 951). The composites consist of a simple and symmetrical bi - directional fabric and SEM images of the same are as shown in Figure 3.The composites were manufactured using the technique of hand layup. The production process involves mixing 100:30 (weight base) of the epoxy resin and hardener. Catalyzed resin mixtures are then speculated on a molding plate of 300 X 300 mm^2.
The precut of the 300 x 300 mm reinforcement layer is applied to the wet epoxy resins. Brush dabbing works out the air. The reinforced layers of the resin are soaked. Eighteen layers are then constructed to achieve a thickness of 3 ± 0.2 mm. Pressure of 0.0965MPa utilized to cure the laminated plates, followed by these are cut to the required size. The size of 5 X 5X 3 mm^3 samples were cut using a diamond cutter from the laminated composites for abrasive studies. After manufacture, as per ASTM D3171 Specifications a resin burn - off test was carried out which determines the fabric content of composite samples. The burn-off experiments were carried out to determine the resin and fiber mass content of the composites. For reinforced epoxy composites basalt of 53.88% and glass fabric of 53.88% fiber weight fractions were found. The fabric of wt percent (x) is based on the following formula,

$$X= (W/W_0) \times 100$$

Where Wo & W is the first after burning weight - off the matrix. The actual composite sample density was determined using a high - precision digital electronic weight balance of 0.1 mg using the Archimedes principle. The difference between theoretical and actual density values results in value of void content. density and void values for laminated composites are as shown in Table I.

B. Scanning Electron Microscope

A scanning electron microscope (SEM) is a type of electron microscope that generates sample images using a focused electron beam. The electrons interact with the atoms of the sample and generate various signals that can be detected and contain sample topography and surface composition information.

TABLE I: Density and void content

Composite	Density (Theoretical) (g/cm^3)	Actual density (g/cm^3)	Void content (%)	Hardness (Shore D)
Glass-Epoxy	1.67	1.61	3.59	69
Basalt-Epoxy	1.76	1.725	1.98	81
Carbon -Epoxy	1.71	1.7	0.59	83

SEM resolution can be better than 1 nanometer. Specimens can be observed In wet conditions or even at a wide range temperatures from cryogenic to any high temperatures, in high vacuum, low vacuum condition (in environmental SEM). The secondary electrons emitted by electron beam atoms are the most common detection method. The number of secondary electrons depends on the angle of the surface to the beam. The pruning of optional electrons is mostly contained on a level surface in the example, but the pruning is uncovered on a tilted surface and more electrons are radiated. Scanning the sample and detecting the secondary electrons create a picture showing the surface tilt. The specimen prepared for SEM analysis is as shown in the Figure 1.

Fig. 1 Samples prepared for SEM

C. Wear Testing

For slide wear experiments, a pin-on-disk setup has been used. The surface (5mmX5 mm), which was attached to an 8 mm diameter and 40 mm long pin, came into contact with a 62 HRc hard disk of En 32 steel, 100 mm diameter, 8 mm thick and 0.84 µm surface roughness. The test was performed on a 60 mm diameter track by selecting the test duration, load and speed as per ASTM G-99. Before testing, the test samples were polished against 600-grade SiC paper to ensure proper contact with the counter surface. The sample and disk surface are cleaned with a soft acetone soaked paper and followed by thorough dry before the test. The pin assembly was initially weighted to a precision of 0.0001 g in a digital electronic balance. The test was carried out for various sliding distances (500 - 2000 m) using a 20 N load and at a constant speed of 200rpm. The slide wear loss measure is the difference between the initial weights and the final weights. For each condition, at least three tests were carried out and average weight loss value was reported.

D. Tensile, Compressive, Shear Testing

The tensile tests results for basalt - E, carbon - E and glass - E composites are as shown in Figure 4. In comparison with the glass fabic-reinforced composites, the basalt fabric type shows an increase of 23% in tensile strength.

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The result shows that, fractured surfaces of the glass - E and basalt - E composite systems. The glass fiber shows a ductile fracture characteristic that tensile resistance plays an important role in matrix - fibre adhesion.

The basalt - E composite test sample showed no shear or debonding failure in the interface of the laminate. The basalt-E composite fracture surface shows the characteristic of a brittle fracture and a small fiber pull-out indicates better adhesion to the fiber matrix.

Better adherence of basalt - E composites to fiber matrix therefore has good tensile properties over glass- epoxy composites. Compression generally induces transverse tension, which results in the debonding of the interface and the resulting shear of the matrix between the fabrics Figure 5 illustrates basalt - E and glass - E composites compression strength. Basalt-E's compression strength is 43.8% higher than Glass-E's compression strength. The increase in compressive strength is due to high hardness basalt fibers. All components were plastically deformed during the compressive test and hard basalt fibers in the matrix were pressed. The prolonged compression makes the hard fibers resist the loads and not plastically deform them. The rigid bond between basalt fibers and epoxy is sufficiently good for load transfer and resistant to higher compression. The micro - buckling compression failure of glass - E composites is due to damage caused by parallel load fibers. For glass-E composites, the micro buckling is characterized. Other researchers have observed similar trends.Due to non supportive nature of matrix and fibers in composites of glass - E leads to the fiber buckle. The formation of microbuckling results in local de - lamination and reduces the compression strength of laminated composites. The inter-laminar shear strength test is used to determine the bond strength of laminated composites between the fiber and the matrix resin. A de - lamination failure occurs in laminated composites between the layers of reinforcing fibers when transverse shear load exceeds inter - laminary shear strength. The better fiber-matrix interface can bind the fibers tightly to withstand the greater load of compression. If vacuums form in the composites, the stress concentration around them significantly deteriorates the load transfer capacity. Formation of high void content among epoxy and glass fabric reduces glass – E inter - laminar shear strength value. Due to the lower void content the inter - laminar shear strength of basalt - E composites was improved and as shown in Table II.

The intensity of the composites ' abrasive wear resistance is calculated by the inverse magnitude of specific wear rate. Figure 2 (c&d) depicts the effect of different loads on the specific wear rates of glass - E & basalt - E composites. The fiber-reinforced composites specific wear rate was (1-5) X10[11] m3 / N-m. As the abrading distance increases for all composite loads results in a linear trend. Different researchers for bi-directional fabric-reinforced composites obtained similar results. Figure 6 & 7 shows the SEM images for minimum load and minimum distance, maximum load and maximum distance. The maximum wear rate was observed for all loads tested for low abrading distance due to the freshness of the grits in SiC grit paper. And the wear rate was gradually decreased as the abrasive grits becomes smooth and less efficient.The basalt – E and glass-E composite displayed the minimum maximum wear rates respectively. This was because during the abrasion, the first resin comes into contact and easily worn out, followed by fibers come into contact with SiC grits. The exposed glass fibers have less hardness in the glass-E composites and are easily damaged by the grains. The presence of Fe in basalt fabric-reinforced composites makes high durability and modulus, Which results in resisting abrasive wear and therefore at all loads has a lower specific wear rate.

IV. RESULTS AND DISCUSSION

The tensile test was performed at 2 mm / min speed using a universal testing machine. The tensile experiments were conducted using specimens 25.4 mm wide and 250 mm long in accordance with the ASTM standard D3039. A uni - axial load on both ends is applied. Five samples for each composite were tested and the average value was taken. The compression tests were carried out in accordance with ASTM D 6641. An Instron 8562 testing machine performed the mechanical properties for the compression test. Short beam testing was conducted to determine inter - laminar shear strength (ILSS) of epoxy composites reinforced with basalt fiber, carbon and glass fiber. The test was carried out in accordance with the ASTM D2344-84on Lloyd LR-100K machine, the ratio span to depth for the specimen was 5:1. ASTM D 2240 specifications shore D Durometer was used to measure the surface hardness of the laminated composites.

TABLE II: Mechanical Properties of Composite

	GE	BE	CE
Tensile strength (Mpa)	250	330	467
Tensile modulus (Gpa)	29.5	56.90	67.09
Compressive strength (Mpa)	170	339	403
ILLS(Mpa)	10	17	18

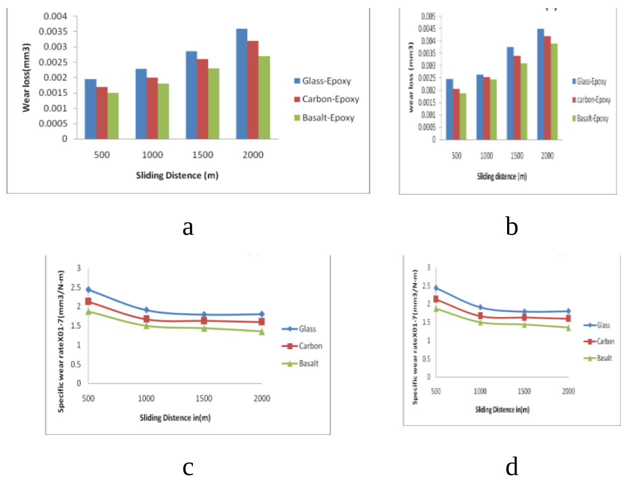
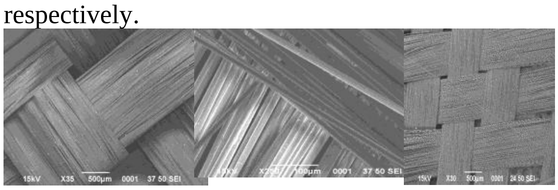


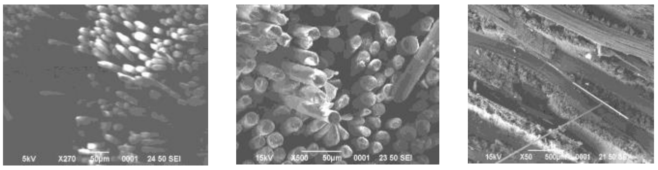
Fig. 2 Result for various materials

In the above Fig 2, (a-b) shows the wear loss at22N and 32 N Fig (c-d) shows the specific wear rate for 22N and 32N respectively.



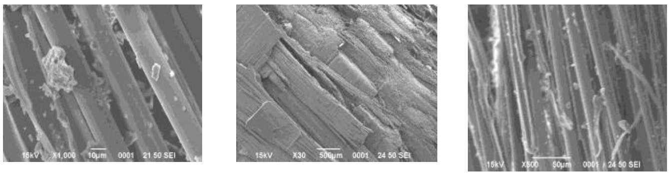
Glass Basalt Carbon

Fig. 3 SEM images of Fibres



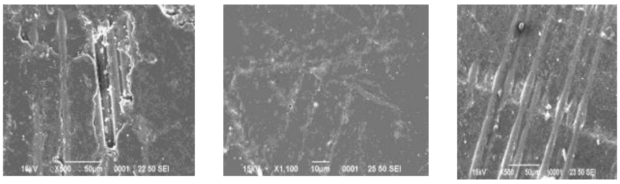
Glass Basalt Carbon

Fig. 4 SEM images for Tension Test



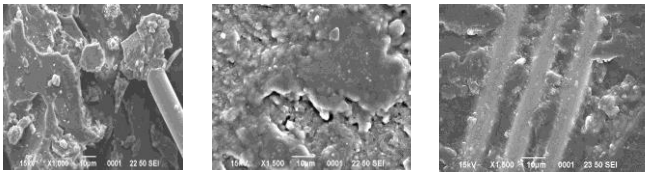
Glass Basalt Carbon

Fig. 5 SEM images for Compression Test



Glass Basalt Carbon

Fig. 6 SEM images for minimum load and minimum distance



Glass Basalt Carbon

Fig. 7 SEM images for maximum load and maximum distance

V. CONCLUSION

- The loss of wear volume in GE composites increased compared to CE and BE composites with an increase in abrading distance.
- Basalt fiber improves abrasion resistance under different loads/abrading distances among the three fibers used. This is due to the high specific strength of the fiber and the nature of self-lubrication. Furthermore, the combination of good fiber and matrix adhesion may be the reason for this improvement in abrasion resistance.
- SEM studies of worn surfaces support the mechanisms involved and have indicated microcracking, chip formation, fiber exposure, cracking of fibers and removal of broken fibres.
- The volume of wear and selected mechanical properties correlated quite well.

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